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LIFE CYCLE COST OF ELECTRICITY GENERATION FROM RICE STRAW IN MALAYSIA: SENSITIVITY ANALYSIS OF ECONOMIC PERFORMANCE

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INTRODUCTION

The limited availability of fossil fuel as a feedstocks is among the key causes for the current transitions toward the use of biomass energy. Alongside the environmental and energy concerns, the economic sustainability of biomass initiatives are considered as key factors in the future development of this sector (Fazio & Barbanti, 2014). Hence, economic analysis on biomass power generation would assess its long-term profit and increase its share in energy mix. According to (Jungingera et al., 2006), however, the high production costs are affecting biomass potential if compared with fossil fuel.

Among the prevailing types of agriculture residues utilized as biomass for electricity production, rice straw notably differentiates itself from other biomass fuels, such as wood, wood residues, and palm oil residues. For example, many researchers are carrying out analyses on the utilization of palm oil residues in power generation. Since the costs of biofuel input mostly depend on the type of biomass resource and its location (Lu¨ schen & Madlener, 2013), therefore paddy residues have been analysed in this paper as feedstocks in electricity generation.

The utilization of rice straw as fuel has gained a large consensus not only worldwide, but also in Malaysia. Studies conducted in Thailand and China agreed with the results to emphasizing on the small-scale power plants to secure supply (Delivand, Barz, Gheewala, & Sajjakulnukit, 2011) and China on the poor management of plants as key factors (Zhang, D. Zhou, Zhou, & Ding, 2013). On the other hand, studies carried out in Vietnam concentrated on the cellulosic ethanol production and estimated the optimal size based on availability of rice straw (Diep, Fujimoto, Minowa, Sakanishi, & Nakagoshi, 2012).

Started in April 2009, the Malaysia Green Technology sector aims to preserve the natural environment and resources by reducing the unfavourable impacts of human actions.

Among the initiatives promoted by the Malaysia Green Technology, is the applied of biomass resources as a derivation of renewable energy was encouraged to develop the sector (Shuit, Tan, Lee, & Kamaruddin, 2009).

Presently, there is a large number of projects which are based on biomass resources as sustainable solutions to ensure Malaysia energy supply in the future. However, the lack of economic analyses on the consumption of rice straw in electricity generation Malaysia determined the still marginal use.

COLLECTED DATA AND METHODOLOGY

The total costs are calculated based on four main operations: rice straw collection, transportation to collection centre (T_1), transportation to power plant (T_2), and plant operation. This study concentrates on the northern regions of Peninsular Malaysia, where the paddy cultivation covers an area of 42% out of 800,000 hectares of arable land. Data were collected by phone questionnaires to 27 District Farmers' Organisation (DFO) managers in Muda Agricultural Development Authority (MADA) to decide the number of areas that are involved in the rice straw collection. Based on the results, only two areas were used to coordinate the collection of rice straw and thus served as unit samples for this research. The total amount of rice straw available in the selected areas is equal to 0.3% of the total supply of rice straw available in MADA areas, where rice straws are commonly used as animal feed as well as burnt if the fields. This study will take into consideration all the present practices for the rice straw management in the areas, such as the standard bale size and the collection centre concept. The parameters of the costs in the examination are based on the average value acquired through the survey.

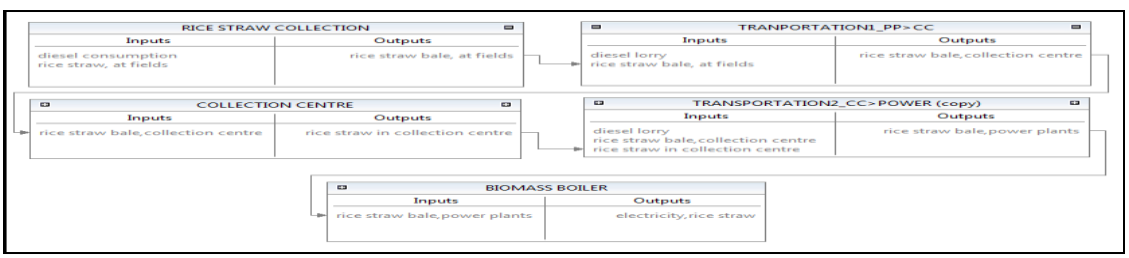


Figure 5.1
System boundaries applied in this study

According to the data available (Caputo, Palumbo, Pelagagge, & Scacchia, 2005; Bridgwater, Toft, & Brammer, 2002; Mitchell, Bridgwater, Stevens, Toft, & Watters., 1995; PDCleanTech, 2014; Energynet, 2012; Boukis, Vassilakos, Karellas, & Kakaras, 2009; Jorgenson, Gilman, & Dobos, 2011; Lako, 2010; Jungingera et al., 2006; R. van den Broek, Faaij, & Wijk, 1996; Dornburg & Faaij, 2001) on different biomass combustions, Figure 5.2 shows the graph of efficiency against plant capacity. Where the majority of data are obtained from real plant operations, some data are sourced from scholarly research. The graph presents the best fit regression curve and the efficiency of the biomass combustion are calculated using Eq. (1). Since in the past the ratio of construction of large biomass power plant was ineffective and considered that the efficiency increases at large plant capacity (>15MW) (Boukis et al., 2009), it was difficult to make the exact forecast of their efficiency at broad combustion (McIlveen-Wright et al., 2013). Therefore, because of restricted data available, the results obtained were rather scarce.

$$\eta = 4.4578 \ln(PPC) + 12.358 \quad (1)$$

Life Cycle Cost

The life cycle costs (LCC) result from the power plant generation cost, the transportation cost, and the rice straw collection cost. The latter one results from the capital cost, operating cost, salvage cost, and feedstock cost.

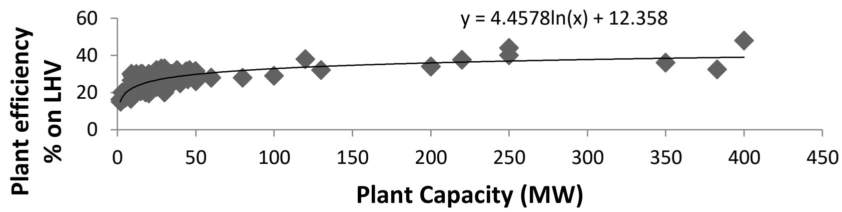


Figure 5.2
Overall efficiency of the power plant

Power Plant Generation Cost

Figure 5.3 is graphed in accordance with the not yet sufficient data on the financial aspects of biomass-based power generation in the Asian countries (CDM, 2014; COGEN3, 2014). The data are sourced from the biomass power plants located in Asia. The experience curve, which concept has been applied in various energy models (M. van den Broek, Hoefnagels, Rubin, Turkenburg, & Faaij, 2009), illustrates the previous course that may be calculated to predict eventual reduction of the costs (Jungingera et al., 2006). However, previous case studies revealed significant limitations in terms of data to determine the empirical curves for the investment costs of biomass, particularly in the case of rice straw-sustained power plant (Jungingera et al., 2006). The developing countries in Asia also present a variance on biomass power plant cost. Based on the available data, the following equation is developed;

$$CC_{PG} = 5060(PPC)^{-0.073} \quad (2)$$

The total plant cost (TPC) for the power plant generation system estimated based on Eq. (3);

$$TPC = CC_{PG} + LC_{PG} + MC_{PG} + OC_{PG} \quad (3)$$

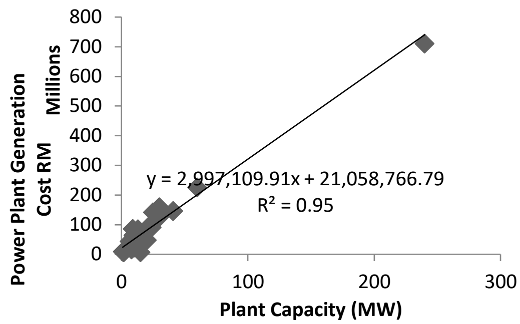


Figure 5.3
Biomass generation cost

Rice Straw Collection Cost

$$C_{DEP} = \left(C_{NEW} - \left(C_{NEW} \times \left(RFV/100\right)\right)\right)/LT \quad (4)$$

The operating cost incorporating the annual maintenance of the machineries is included in Eq. (5) and Eq. (6) (Painter, 2011; Delivand, Barz, & Gheewala, 2011; Huisman, Venturi, & Molenaar, 1997). The parameters chosen for assessing the operating cost are entered in Table 5.1. The average consumption of diesel is given in Eq. (7).

Table 5.1
Machinery operating cost

Machine	Cost (RM)	Depreciation (RM)	AMI (RM)	THII (RM)	Repair Cost (RM)	Total (RM)
B-II						
New Holland	75000	3646	47655	5051.43	49218.80	9189.62
Fiat	60000	2916	38124	4041.14	39375	7351.69
Farm track	50000	2430	31770	3367.62	32812.5	6126.41
Dongfeng	65000	3159	41301	4377.91	42656.2	7964.34
Baler	100000	5133.3	61500	7318.50	107500	23201.83
F-IV						
New Holland	75000	3646	47655	5051.43	492.19	9189.62
New Holland	75000	3646	47655	5051.43	492.19	9189.62
New Holland	75000	3646	47655	5051.43	492.19	9189.62
New Holland	75000	3646	47655	5051.43	492.19	9189.62
Baler	100000	5133.3	61500	7318.50	10750	23201.83

$$C_{RM} = C_{NEW} \times ARM_C / LT \tag{5}$$

$$ARM_C = (RF1) \times (h/1000)^{RF2} \tag{6}$$

$$C_F = 0.73 \times 0.06 \times PTO \times P_F \times h \tag{7}$$

Table 5.2 shows the results for the machinery operating costs for B-II and F-IV areas that are based on the interview session occurred with the project manager of B-II area (Sabri, 2012). and the secondary data resulted from (Sabri, 2012) and (Malik, 2012). As illustrated in Table 5.1, the average cost of rice straw collection for both areas is RM 26.09 per bale. These costs include the sleaser cost, RM 8 per bale, as the management would return RM 69.50 per ha to the farmers who are not willing to execute the cutting process in their fields (Malik, 2012; Sabri, 2012).

Table 5.2

Total cost of rice straw collection (per bale) in the northern regions, Malaysia.

Zone	Fuel (RM)	Labour (RM)	Twine (RM)	Machinery (RM)	Total (RM)
BII	1.78	6	1.64	17.62	27.04
FIV	1.52	6	-	17.62	25.14

Table 5.3

Rice straw based electricity generation costs.

Project financing	20MW	30MW	50MW	70MW	100MW
Equity (RM 10^6)	45.04	62.92	97.97	140.93	195.63
Dept (RM 10^6)	105.11	146.82	228.59	328.85	456.47
Annuity, An (RM 10^6)	13.61	19.01	29.60	42.59	59.11

Cost of Transportation Rice Straw to the Collection Centre (TC_1)

The transportation cost from the paddy fields to the collection centre is shown in Eq. (8) and determined by the transportation distance, lorry dimension, and driver cost (Leboreiro & Hilaly, 2011; Chiueh, Lee, Syu, & Lo. 2012). The contribution to the driver is based on number of bales, where each bale is RM5 (Sabri, 2012). Concerning the capacity, a lorry transporting 1 tonne of rice straw is assumed to consume 0.105litre per km, whilst transporting 2 bales of 450 kg each would cost RM1.80 of diesel per litre (MIDA, 2013). The following total transportation cost (CT_1) is comprehensive of all costs required for moving the rice straw bales to the collection centre.

$$CT_1 = \left(\left(0.105 * F * d_{aT1} / L_{T1}\right) + \left(CP_{T1}\right)\right) * BRS \tag{8}$$

Collection Centre Cost

This paper presents a rice straw collection model on the basis of a previous study. The catchment area increases correspondingly with the plant capacity. Currently operating collection centres are at B-II and F-IV, which concept of open storage is used as guideline for this case study. The accumulation of rice straw in this area is relatively limited as the residue is mostly used as animal consumption. The total cost of this collection centre derived from the total of the storage site and the cost of dry matter lost during the conservation (Turhallow, Wilkerson, & Sokhansanj, 2009). The amenity used as storage has impact on the storage cost. The baler is kept in an open storage because round bales are less vulnerable towards adverse climate conditions (Gold & Seuring, 2011).

$$3C_{A,CC} = PP \times \left(i/1-(1+i)^{-n} \right) \tag{9}$$

Where $C_{A,CC}$ is the annual capital cost (in RM), PP is the purchase price (in RM), i is interest rate and n life of investment year, and DML is dry matter loss in the collection centre (in tonne).

$$C_{CC} = \left(C_{A,CC}/W_{CC} \right) \times \left(1/1-DML \right) \tag{10}$$

The Cost of Transportation of Rice Straw from the Collection Centre to Power Plants (TC_2)

The cost of the transportation of rice straw to power plant is shown in Eq.11. The cost related to the driver depends on the travel distance, which is usually charged RM4 per km. Due to the affordable price, trucks measuring the weight of 3.5 or 40' length are mainly used to transport the balers (Malik, 2012; Sabri, 2012) as they can travel distance greater than 35 km (Ruiz , Jua´rez , Morales, Mun˜oz , & Mendı´vil, 2013) and move 36 balers at time. The average fuel expenditure is 0.27 litres per km (Chiueh et al., 2012). The location of the power plant is selected according to the proximity with a coal power plant.

$$CT_2 = (((0.27 * F * d_{aT2}) + (CD * d_{aT2}))/L_{T2}) * BRS \tag{11}$$

Salvage Cost

The salvage value is the residual value of the components and capital of a rice straw-based power production in the furthest phase of the project. The current value of salvage cost is measured in the equation 13 (Ong, Mahlia, Masjuki, & Honnery, 2012) that shows its annual devaluation rate, d= 10%.

Contingency

The banks grant about 70% of the total capital cost needed with an annual interest rate is 5% for 10 years. Eq. (12) is the estimation of the allocation (Boukis et al., 2009).

$$An = L * \left(r(1+r)^n / (1+r)^n - 1 \right) \tag{12}$$

Sale of Electricity

Electrical energy is assumed to be supplied to the Tenaga National Berhad (TNB) at 21.25 cents/kWh. The sales value of the operating plants is estimated to be RM37.2, RM55.8, RM93.1, RM130 and RM186 millions per year for plant capacities of 20MW, 30MW, 50MW, 70MW and 100MW respectively.
The proportion of the total cost utilization comprises the capital cost, fuel, and operation to the net electricity generation in RM/kWh.

RESULT AND DISCUSSION

Detailed operation costs are illustrated in Table 5.4. The reduction of the TC_2 distance can lower the fuel cost up to 25% and secure RM59.04 per bale ready at power plant gate. Though, the TC_1, which is the amount of the bale rice straw transport from the paddy fields to the collection centre, only contributes 16.6% for 20 MW up to 29.3% for 500 MW.

Table 5.4
Detailed operation costs of the selected power plants

Power Plant Capacity (MW)	**20**	**30**	**50**	**70**	**100**
Efficiency	25.7	27.5	29.8	31.3	32.9
Electricity generation (MWh/yr)	175200	262800	438000	613200	876000
Rice straw available (t/yr)	177498	248760	382915	510388	693875
Power Plant Cost (RM 10^6)	82.1	112.0	171.9	231.8	321.7
Collection Centre Cost (RM 10^6)	2.2	3.1	4.8	6.3	8.6
Rice straw collection cost (RM 10^6)	10.3	14.6	22.5	29.9	40.7
Transportation cost (RM 10^6)	18.8	26.6	41.7	56.3	77.7

The plant capacity has a considerable repercussion on the economic feasibility which can be compensated by the price of biomass (Uris, Linares, & Arenas, 2014). Similar to the result obtained from the previous study on gasification technique for biomass in power generation in Canada, where COE decreases considerably as plant capacity increases (Upadhyay, Shahi, Leitch, & Pulkki, 2012). According to (Rendeiro, Macedo, Pinheiro, & Pinho, 2011), the study of biomass utilization increases when the output is greater than 10MW.

$$PPC_{FUEL} = -3\times10^{-5}\,PPC^2 + 0.0306PPC + 78.358 \quad (13)$$

$$PPC_{COE} = 0.893(PPC)^{-0.088} \quad (14)$$

To make the business of selling the electricity profitable, power plants should be designed with at least 500MW and based on lower COE if compared to the purchasing price of TNB at RM0.2125 per kWh. The fuel cost inclusive of all expenses from the collection to the plant per bale ready at 20MW plant capacity is RM 78.27, but it can go up to RM87.03 at higher plant capacity size, as 500MW. Since transportation mainly conditions the total fuel cost, the bigger the plant capacity the higher the fuel cost. The parameter that largely affects the COE is the investment cost, also called capital cost. Similarly, studies conducted in China concluded that the total investment cost primarily affect the higher power generation cost (Zhang et al., 2013), although this cost would lower with time. Increasing the size of plant can minimize the generation cost by 0.08% to 3%. Figure 5.4 illustrates the yearly capital for 20 years of a plant life, from year 2013 to 2033. Figure 5.5 shows the payback period on own investment with 20MW, 70MW and 100MW plant capacity. For example, the payback period for 70MW is 5 years when the annual cash flow is RM25.7 million. The payback period is shortened when the plant capacity increases following the result obtained from rice straw combustion in Thailand (Delivand, Barz, Gheewala & Sajjakulnukit, 2011).

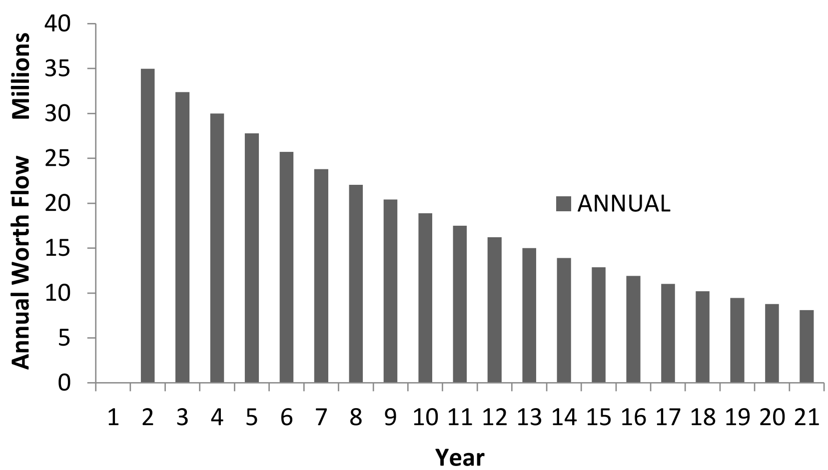


Figure 5.4
Annual cash flow, starting from year 2013 to 2033

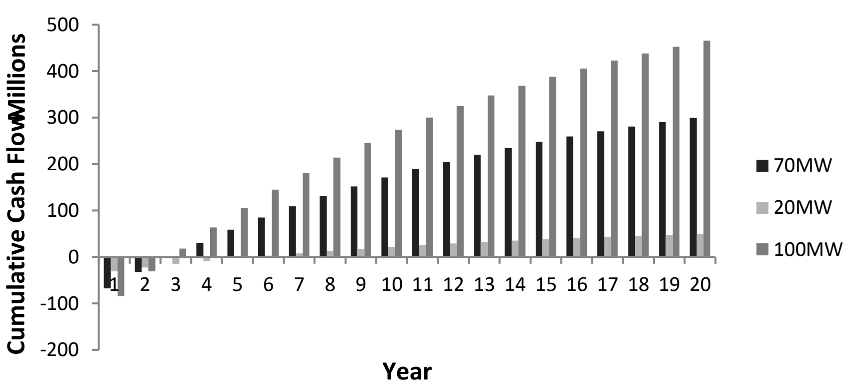


Figure 5.5
Payback period on own capital with 20MW, 70MW and 100MW plant capacity

Table 5.5

Evaluation of projects' finance

Criteria	Plant capacity				
	20	30	50	70	100
NPV (RM 10^6)	28.9	69.9	162.0	259.6	410.4
COE(RM/kWh)	0.72	0.67	0.62	0.59	0.57

The evaluation of the projects' finance is shown in Table 5.5, in which the impacts of the scale on the COE are examined over the selected sort of dimensions. It resulted that the generation costs for the 100MW are around 15% lower than the 20MW.

Figure 5.6 presents the connection between the NPV and the discount rate. Discount rates are at 10% for plant which capacity is less than 20MW, and go up to 20% for the biggest plants (100MW). All these parameters are fundamental for reaching the break-even point of power plant operation.

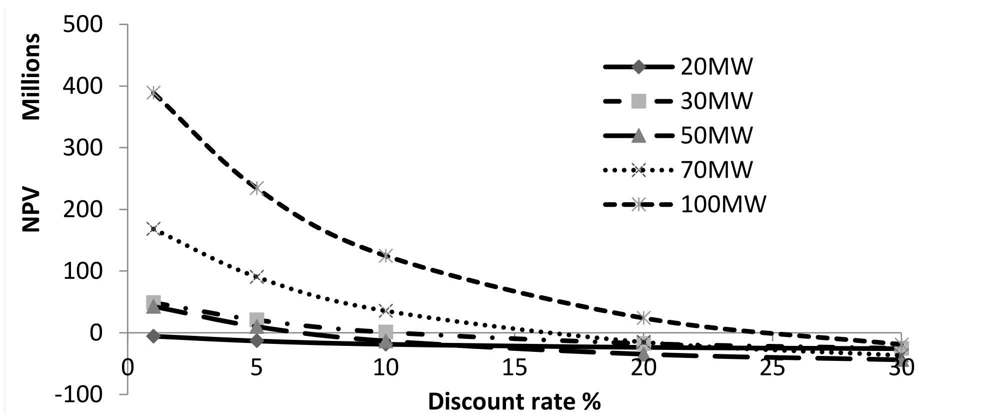
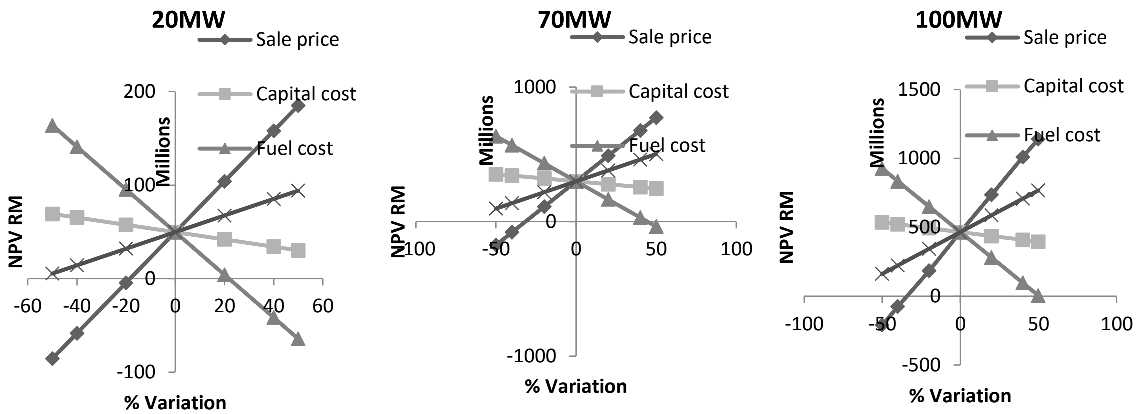


Figure 5.6
Correlation between the NPV and discount rate

The sensitivity analysis on the major parameter that impacts the NPV is graphed in the Figure 5.7. The slopes of the line represent the correlation between NPV and the parameters; if the line representing the parameters is steep, then their influences on NPV are greater. The Figure 8 also shows that at lower power plant capacity, the significance of selling price, discount rate, and fuel cost is almost equal. These parameters slightly change when the plant capacity increases. At 100MW, discount rate largely affects the NPV.

Incentives and Regulations in Renewable Energy Resources

In this paper, the analysis considered the incentives implemented by the national energy policy for the exercise of renewable energy resources, in which 70% is tax reduction from total profits and application of FiT for plants which capacity is less than 30MW. Figure 5.8 shows the payback period after the use of the incentives on 70MW capacity' plants. The payback period is reduced from 5.5 years to 4 years. The NPV increased to RM352 million due to the 70% reduction of tax price, FiT for 30MW plant capacity and bonus of RM0.01 per kWh because of the use of steam-based electricity production process with total productivity higher than 14%. Therefore, under certain conditions, incentives that sustain the implementation and application of biomass resources is necessary to make the latter ones attractive (MacFarlane, 2009). At the present time, government support is necessary for power generation plants to continue and advance (Yang et al., 2014).



(a) (b) (c)

Figure 5.7
NPV sensitivity analysis on (a) 20MW, (b) 70MW and (c) 100MW.

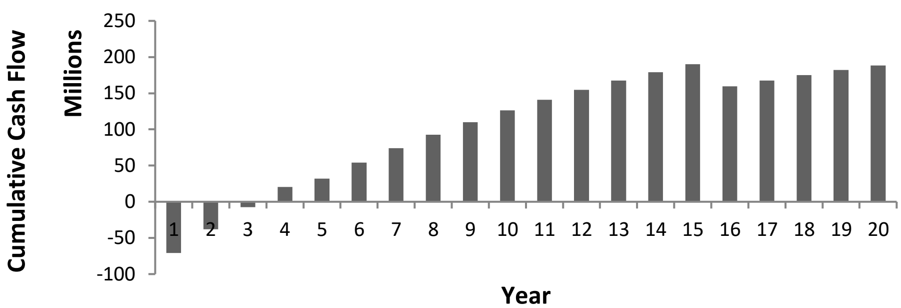


Figure 5.8
Project payback period for own capital (incentive applied).

CONCLUSION

Life cycle cost system comprehends the process of rice straw collection, collection centre cost, transportation, and power generation. Among these elements, transportation impacts the total operating cost at an average of 82.5%. The calculated electricity generation costs are between RM0.72 per kWh to RM0.53 per kWh for 20MW to 500MW, respectively. COE is reduced of about 0.001% each MW plant capacity's increase. Due to high costs of overall operation and capital, the COE is generally higher than purchasing price of TNB, except from the case in which the plant capacity is larger than 20MW. The component that influences the most the COE is the investment cost, although it would reduce with time. The payback period for a plant capacity of 70MW is 6.5 years and the annual cash flow is RM13.5 million. The sale price variation was the most relevant in relation to the NPV.

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